

Fabrication of nanodevices using AFM nanolithography and manipulations

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Proximal probes like the scanning tunneling- and atomic force microscopes (STM and AFM) are frequently used as versatile tools, not only for imaging, but also for controlled modifications of surfaces, nanolithography, and manipulations of nanostructures. Here I present a review of these techniques and their use for the fabrication of nanometer scale devices.

I will first present a detailed study of the anodic oxidation of silicon using the tip of an AFM. We have investigated the kinetics of the AFM tip induced local oxidation of silicon surfaces. Depending on electrical field strengths and stress which builds up at the Si/SiO₂ interface the oxidation kinetics may vary over up to 6 orders of magnitude. We will discuss the capabilities of this technique as a tool for the fabrication of electronic devices with respect to writing speed and spatial resolution.

As an example, the AFM nanolithography technique has been used in the fabrication of ultra-short channel MOSFETs at the bottom of a V-groove. The active channel of the transistor is undoped and defined by a combination of AFM patterning and anisotropic etching of a n⁺⁺ layer grown on a silicon insulator (SOI) wafer. The etching method is self-limiting and produces V-groove MOSFET devices with less than 10nm channel length. The V-groove MOSFET with a source/drain separation of less than 40nm exhibiting state-of-the-art electrical characteristics will be presented. This method allows exploring the ultimate scaling limits of MOSFETs and testing theoretical work on the properties of these nanoscale devices.

In the second part, I will discuss the use of AFM to control the shape and position of individual carbon nanotubes dispersed on a surface. Specifically we can bend, straighten, translate, rotate, and under certain conditions, cut nanotubes. Such manipulations are feasible due to the interaction between nanotubes and the substrate, which can stabilize highly strained nanotube configurations.

These manipulations have been used to fabricate molecular size devices using carbon nanotubes and study their properties. The nanotubes can be metallic or semiconducting depending on the folding angle and the diameter. Using manipulations, we can selectively fabricate devices of either metallic or semiconducting nanotubes. The metallic devices present exceptionally high current carrying capabilities before breakdown and very low resistance, resulting from a very weak electron-phonon coupling in this system. The semiconducting nanotubes can be used as active channels of field-effect transistors (FETs). I will present results on making nanotube FETs with optimized performance and discuss the potential use of metallic nanotube for interconnects. The fabrication of a good gate coupling using different dielectric material will also be discussed. The characteristics of the nanotubes

transistors will be benchmarked with silicon MOSFETs and shown to be comparable. Finally, I will present the fabrication of various logic circuits based on nanotubes using complementary p- and n-type nanotube FETs.

*Work done in collaboration with Ph. Avouris, J. Appenzeller, V. Derycke, J. del Alamos, J. Knoch, , T. Hertel and P. Solomon

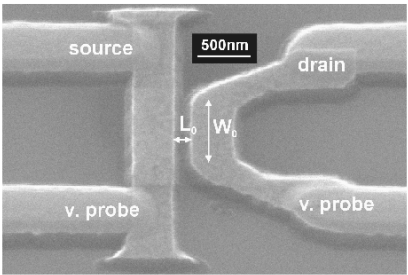


FIG. 1. SEM top view of a V-groove MOSFET before gate oxidation and gate metal deposition. L_0 is the V-groove opening, W_0 the nominal transistor width of around 700nm. Two source and two drain contacts are connected to allow to perform four-terminal measurements.

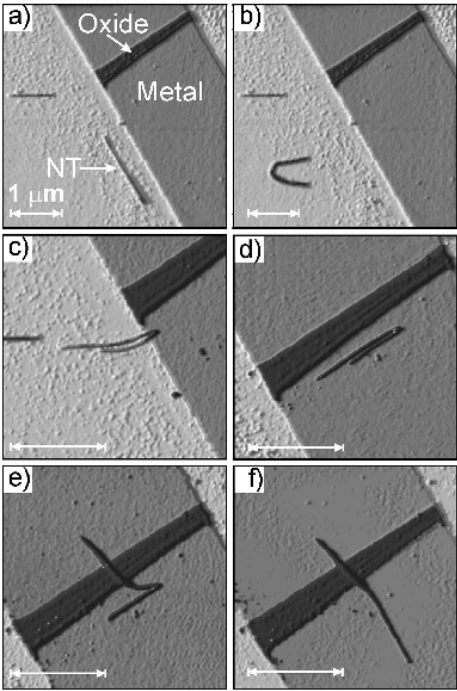


Fig.2 AFM manipulation of a single multi-wall nanotube such that electrical transport through it can be studied. Initially, the nanotube NT is located on the insulating SiO₂ part of the sample. In a stepwise fashion not all steps are shown it is dragged up the 80 Å high metal thin film wire and finally is stretched across the oxide barrier.